US 20030206691A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2003/0206691 A1**

Puzey (43) **Pub. Date: Nov. 6, 2003**

(54) **HIGH SPEED DATA LINK AND TRANSMITTER IN THE MID-INFRARED WAVELENGTH RANGE**

(76) Inventor: **Kenneth A. Puzey**, Essex Junction, VT (US)

Correspondence Address:
BOULDER PATENT SERVICE INC
1021 GAPTER ROAD
BOULDER, CO 803032924

(21) Appl. No.: **10/435,157**

(22) Filed: **May 10, 2003**

Related U.S. Application Data

(63) Continuation of application No. 09/815,972, filed on Mar. 22, 2001, now Pat. No. 6,584,245, which is a continuation-in-part of application No. 09/637,098, filed on Aug. 10, 2000, now Pat. No. 6,285,487, which is a continuation of application No. 09/208,326, filed on Dec. 9, 1998, now Pat. No. 6,115,170, which is a continuation of application No. 08/643,642, filed on May 6, 1996, now Pat. No. 5,768,002.

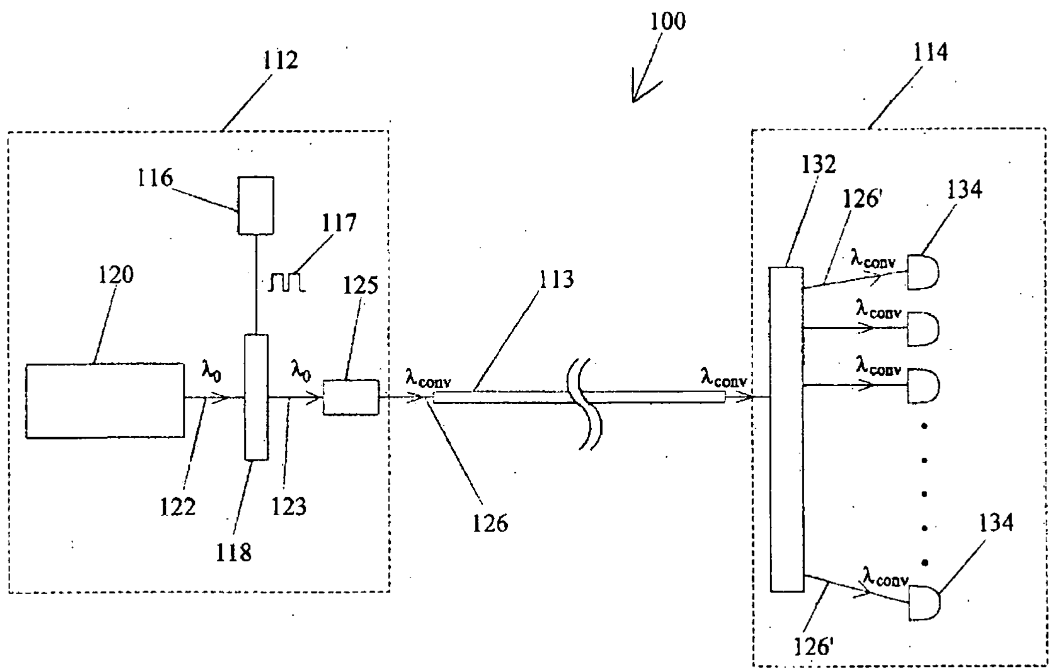
Publication Classification

(51) **Int. Cl.**[7] **G02B 6/28**

(52) **U.S. Cl.** **385/24**

(57) **ABSTRACT**

A mid-infrared transmitter for providing a light signal in a free-space communication system includes an arrangement for producing electromagnetic radiation having a certain wavelength in a mid-infrared wavelength range. The mid-infrared transmitter further includes an arrangement for modulating the electromagnetic radiation so as to provide a train of light pulses having the certain wavelength as the light signal.



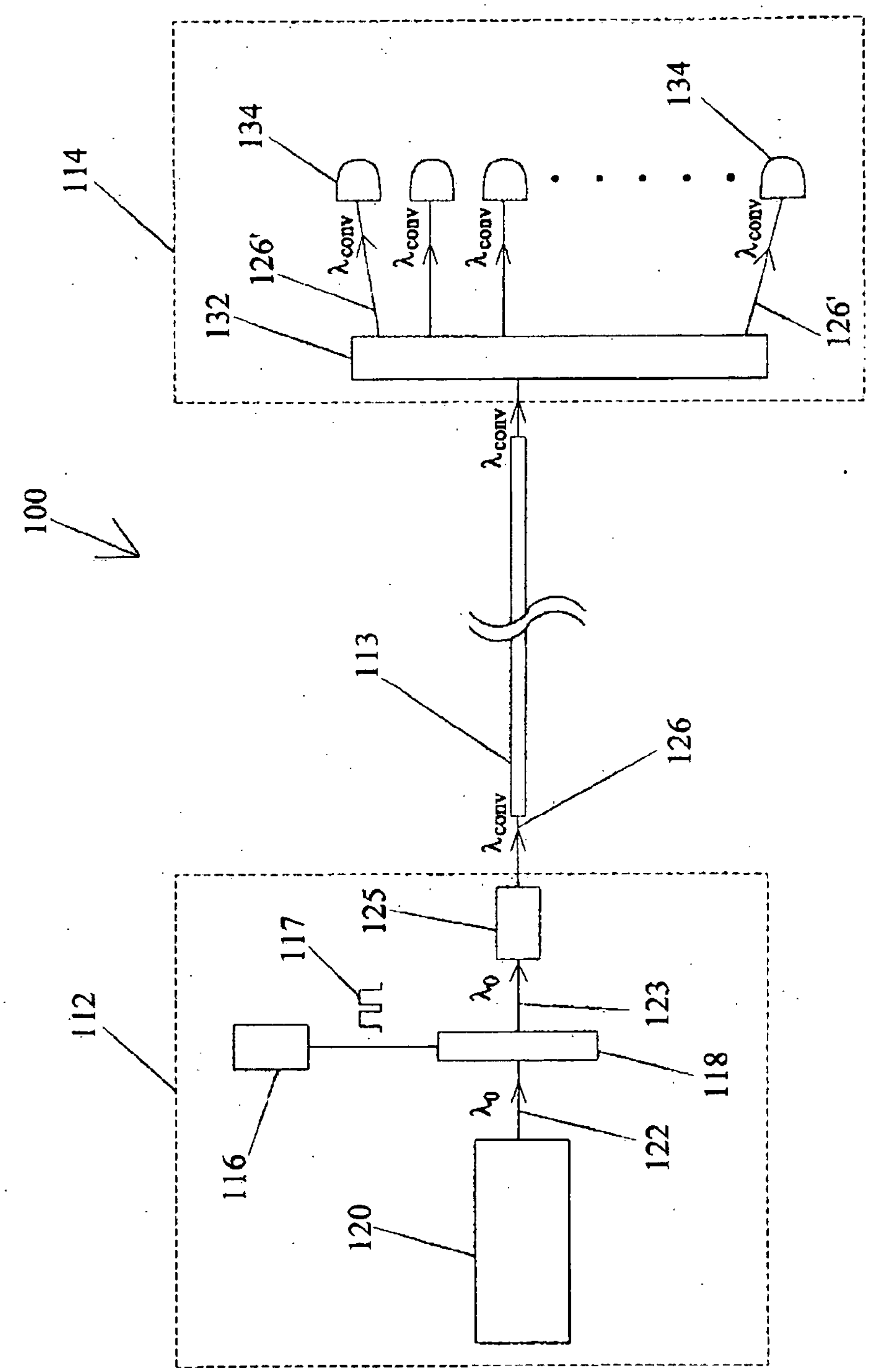

100
112
114
113
116
117
118
120
122
123
125
126
126'
132
134
λ_0
λ_{conv}

FIG. 1

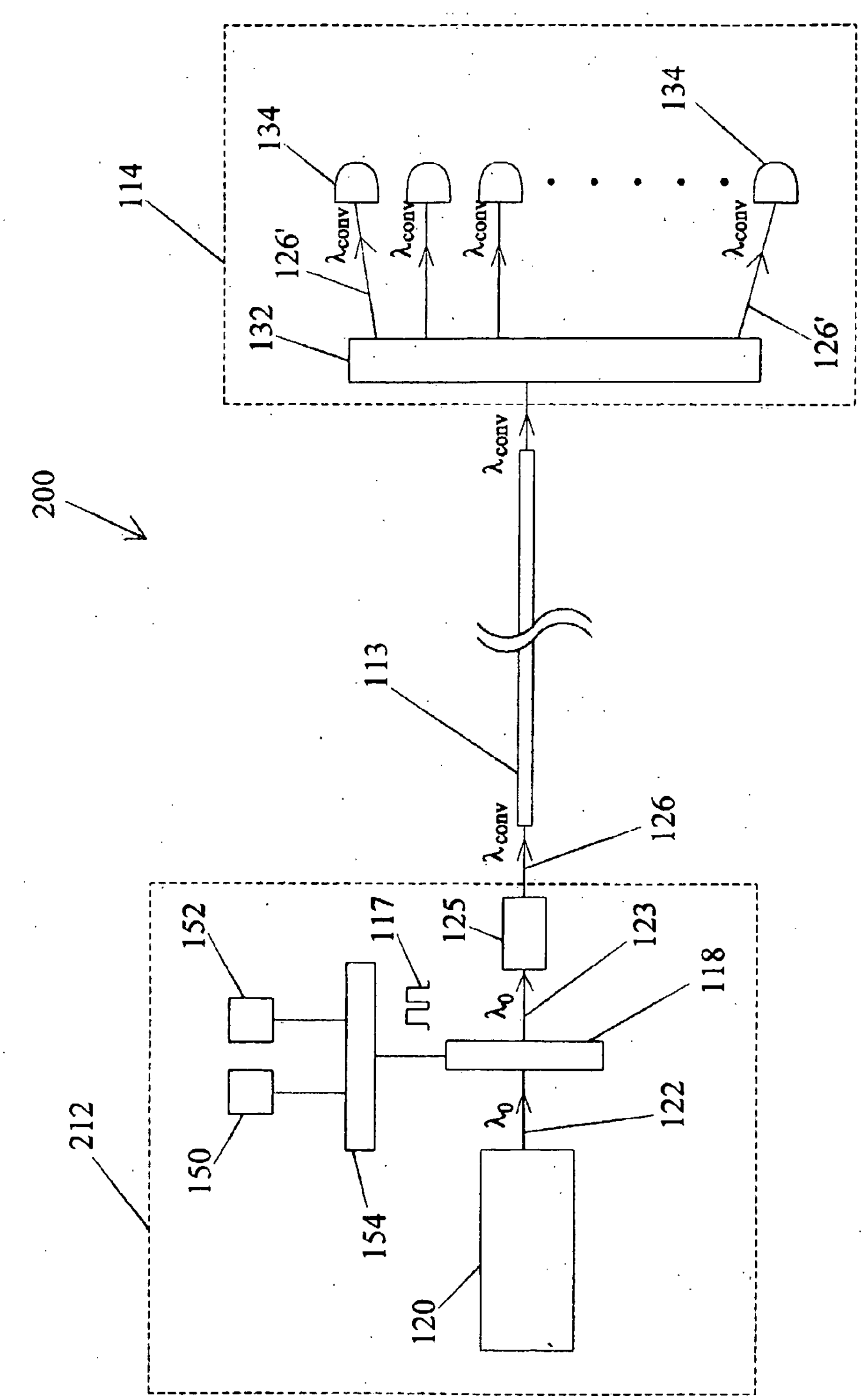

200
212
120
122
λ_0
118
123
λ_0
125
117
152
150
154
126
λ_{conv}
113
λ_{conv}
114
132
126'
λ_{conv}
134
134
126'

FIG. 2

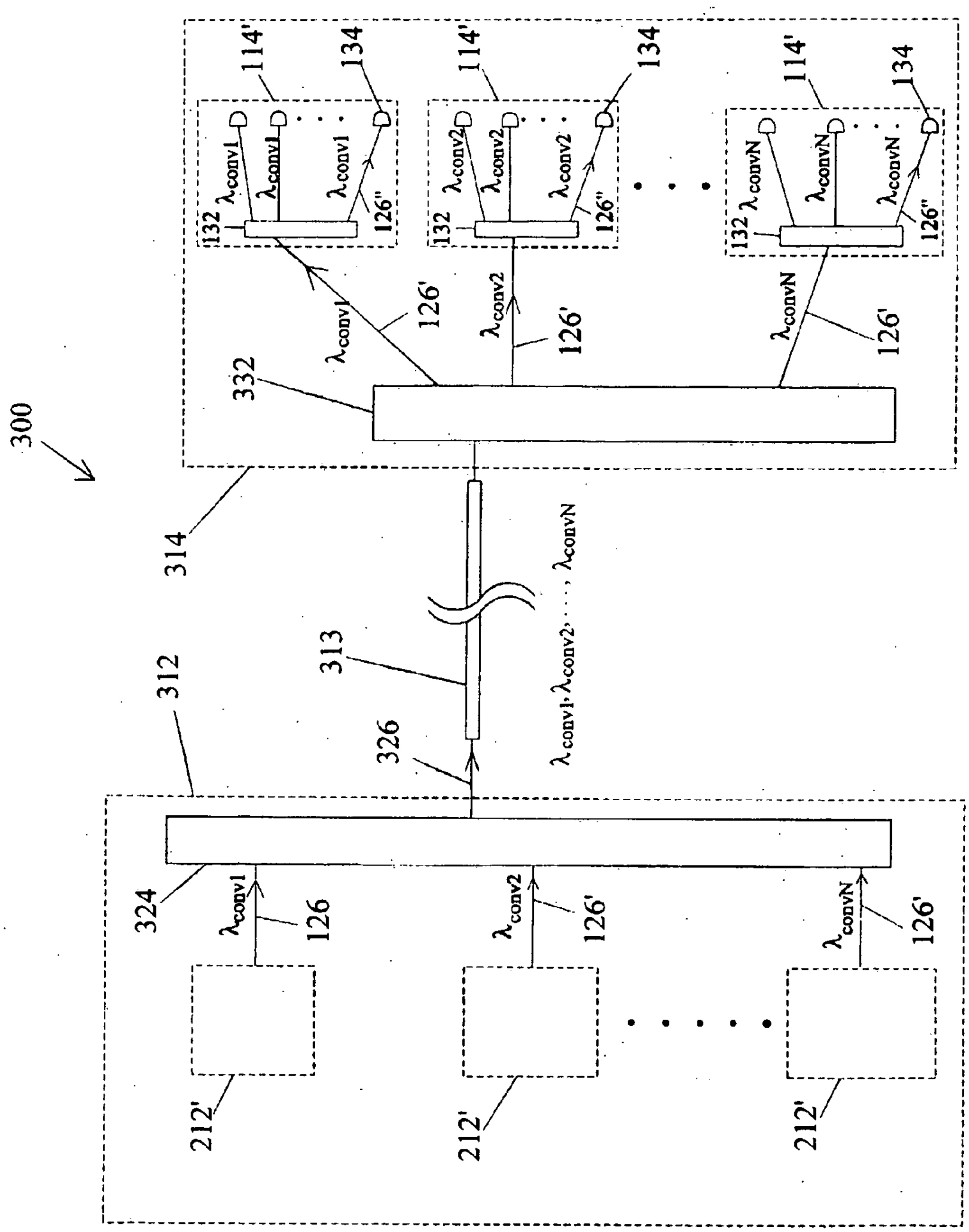

300
314
312
313
326
324
332
114'
134
132
126"
126'
126
212'
λ_{conv1}
λ_{conv2}
λ_{convN}
$\lambda_{conv1}, \lambda_{conv2}, \ldots, \lambda_{convN}$

FIG. 3

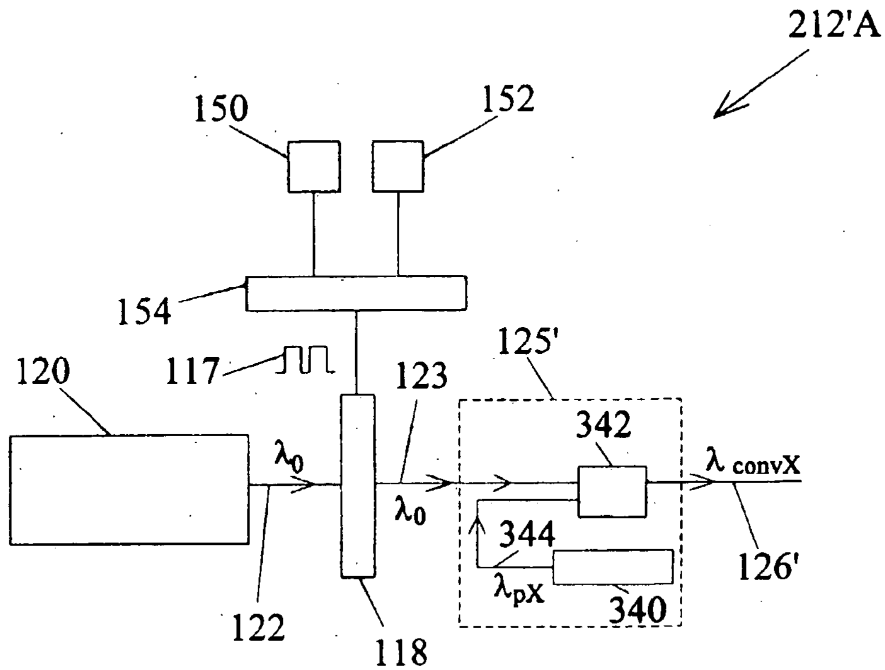

212'A
150
152
154
117
120
123
125'
342
λ convX
λ0
λ0
344
λpX
340
126'
122
118

FIG. 4A

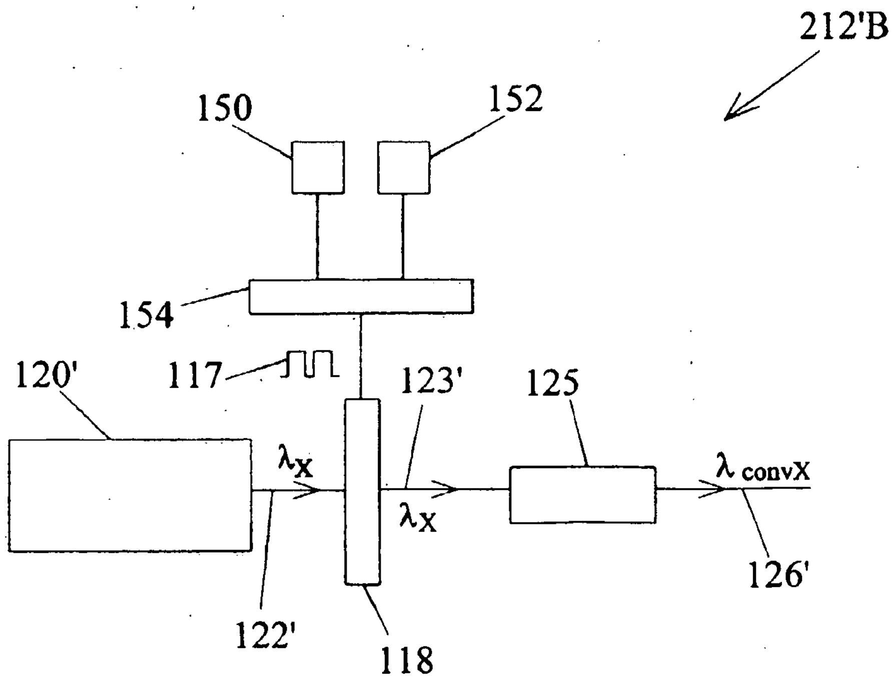

212'B
150
152
154
117
120'
123'
125
λX
λX
λ convX
126'
122'
118

FIG. 4B

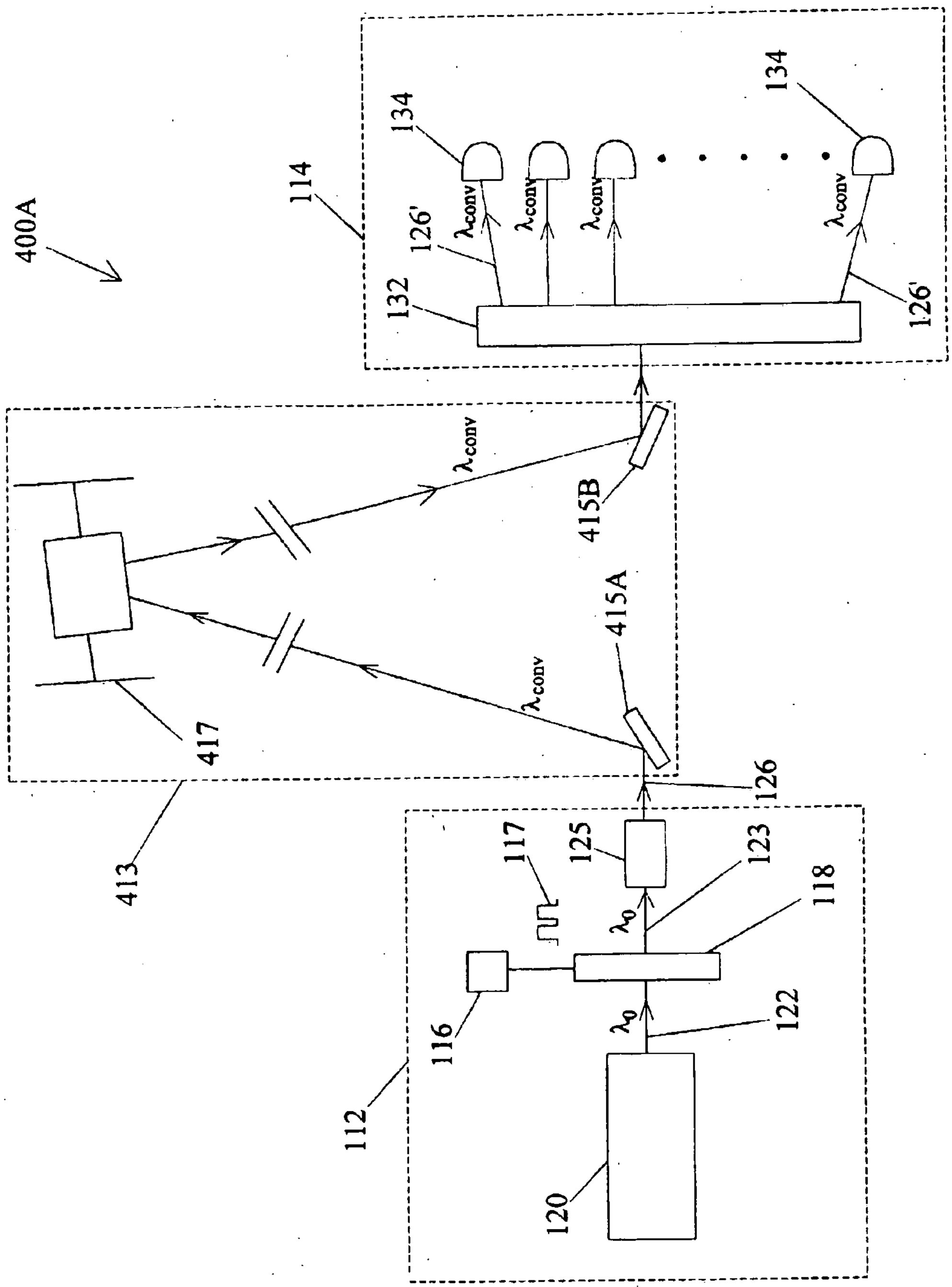

400A
114
134
134
126'
126'
132
λ_{conv}
415B
415A
417
413
126
125
117
123
118
λ_0
122
116
112
120

FIG. 5A

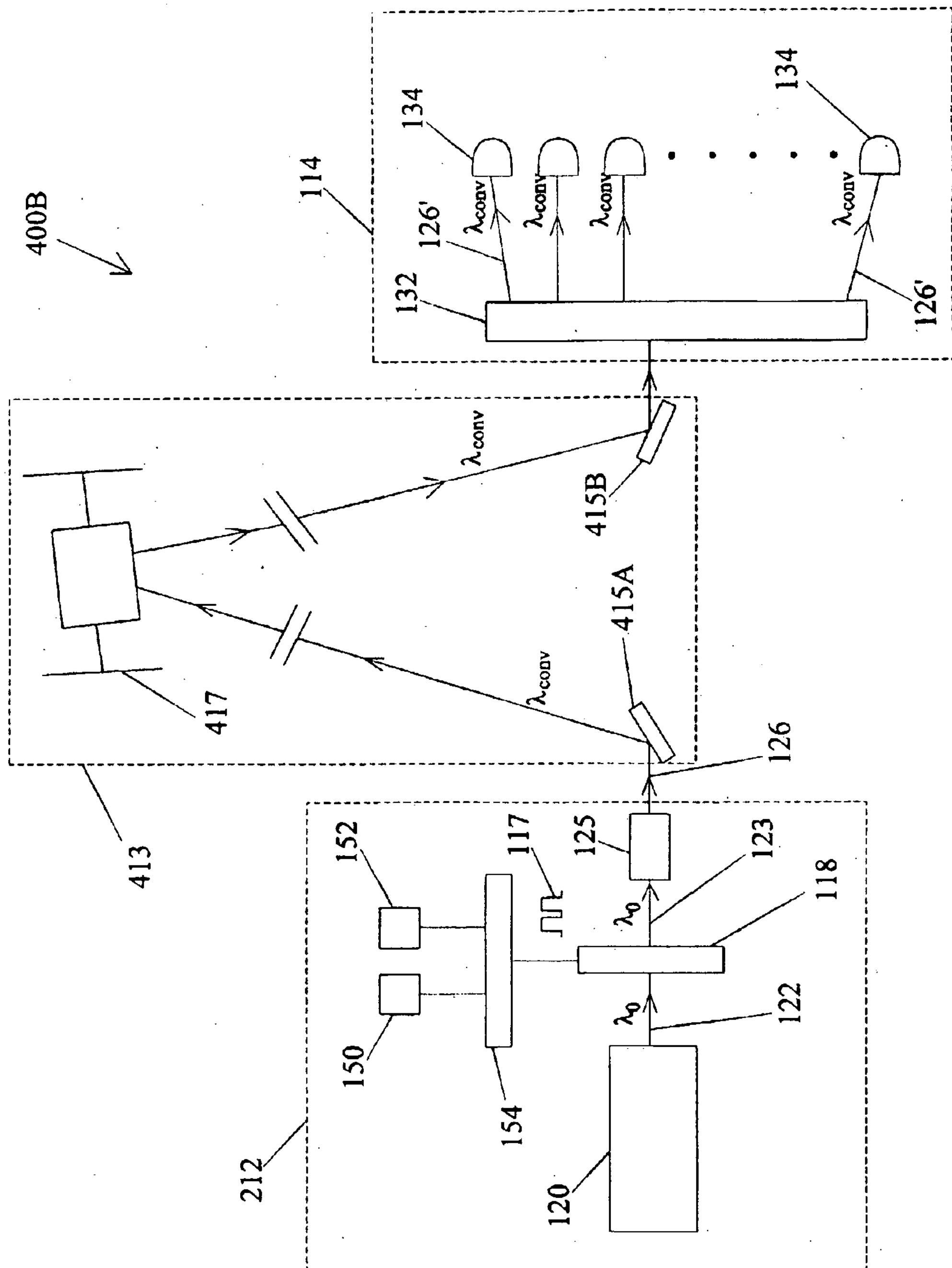
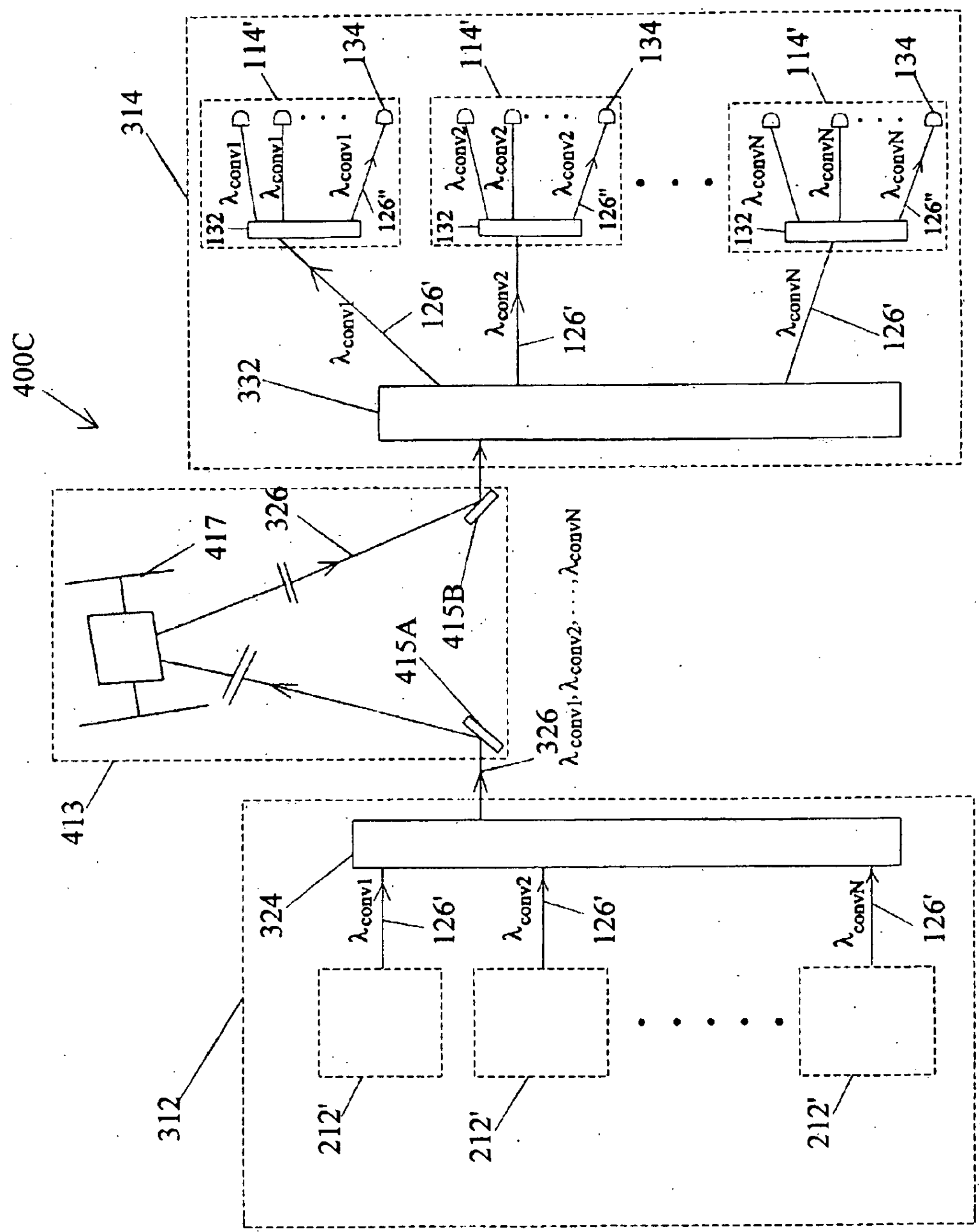

400B
114
134
134
126'
132
126'
413
415B
415A
417
126
212
152
150
154
117
125
123
118
122
120

FIG. 5B



400C
314
114'
134
132
126"
126'
332
413
417
326
415A
415B
324
312
212'

FIG. 5C

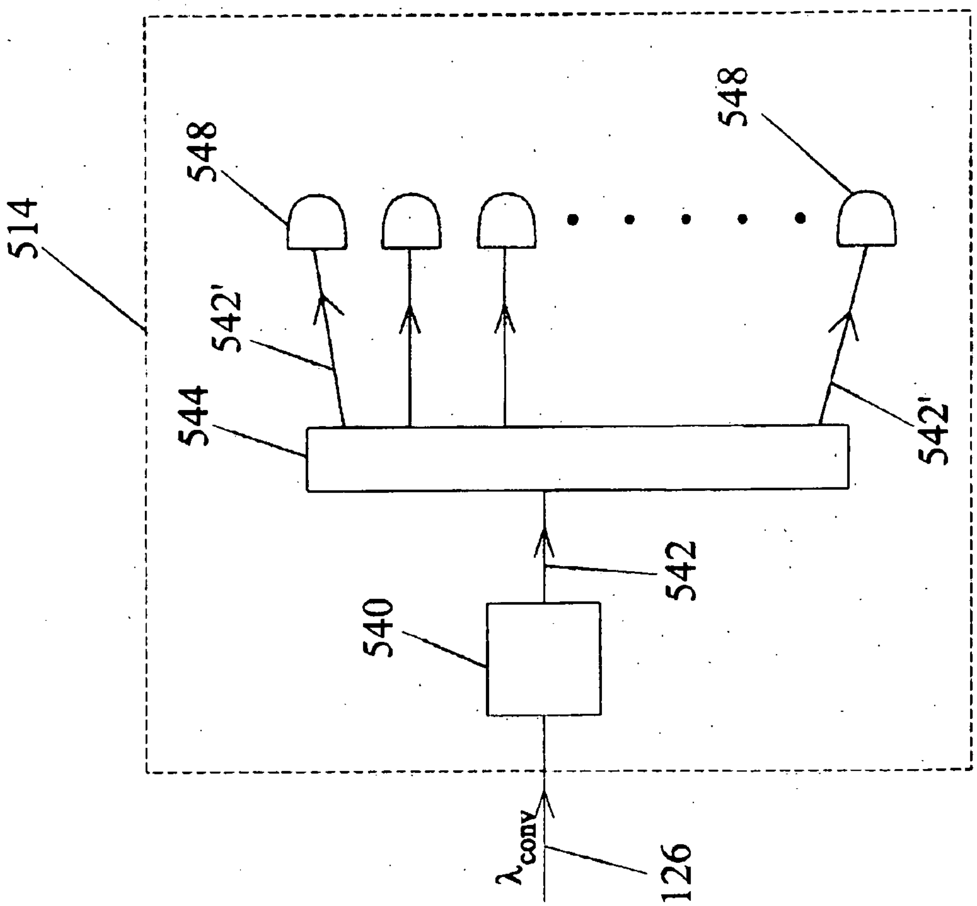


FIG. 6

HIGH SPEED DATA LINK AND TRANSMITTER IN THE MID-INFRARED WAVELENGTH RANGE

BACKGROUND OF THE INVENTION

[0001] The present application is a continuation of copending U.S. patent application Ser. No. 09/815,972 filed Mar. 22, 2001, which is a continuation-in-part of U.S. patent application Ser. No. 09/637,098 filed Aug. 10, 2000 and issued Sep. 4, 2001 as U.S. Pat. No. 6,285,487, which is a continuation of U.S. patent application Ser. No. 09/208,326 filed Dec. 9, 1998 and issued Dec. 5, 2000 as U.S. Pat. No. 6,115,170, which is a continuation of U.S. patent application Ser. No. 08/643,642 filed May 6, 1996 and issued Jun. 16, 1998 as U.S. Pat. No. 5,768,00. All of the aforementioned patent applications and patents are incorporated herein by reference in their entirety.

[0002] The present invention relates generally to fiber optic communications and, more particularly, to high speed data links for use with light modulation systems including a superconductive plate assembly in a data transmission scheme.

[0003] The light modulation system as disclosed in U.S. Pat. No. **5,768,002** is capable of transmitting optical data signals at high data rates such as, for example, rates of terabits per second (Tbit/s) at a given wavelength over a single optical fiber. For example, the light modulation system can be used in a wavelength-division multiplexing (WDM) system to provide the optical data signal at a WDM channel.

[0004] However, in order to achieve a complete data link capable of handling optical data signals at a single wavelength at Tbit/s rates, an optical receiver in the data link must be able to detect the optical data signals at Tbit/s rates. Such an optical receiver singly capable of detecting Tbit/s optical data signals of a single wavelength is not commercially available at the present time to the applicant's knowledge. Although optical detectors capable of detecting optical signals at a rate of 750 GHz or with response times on the order of picoseconds or less are known in the art, these devices are still in their experimental stages hence are not yet commercialized.

[0005] Prior art data links have not had to deal with this problem of the unavailability of Tbit/s rate optical receivers because light modulation systems capable of transmitting optical data signals at Tbit/s rates at a given wavelength are not currently known at this time to the applicant's knowledge, with the exception of the light modulation system disclosed in U.S. Pat. No. 5,768,002. Existing high speed light modulation systems generally consist of a series of N light modulators, each light modulator corresponding to one channel out of N channels and producing optical data signals at rates of less than Tbit/s at a unique wavelength corresponding to a particular WDM channel out of a range of wavelengths λ_1-λ_N. The multitude of optical data signals over the range of wavelengths, each optical data signal having its own unique wavelength, are multiplexed onto an optical fiber. The multiplexed signal is received by a demultiplexer which separates the multiplexed signal into the separate optical data signals according to wavelength. The separated optical data signals are then detected by a plurality of optical detectors, each operating at less than Tbit/s rates.

[0006] The prior art data link as a whole can be made to transmit data at Tbit/s rates by using a plurality of data sources, optical sources and optical detectors all operating at Gbit/s rates. For example, if a hundred optical sources are provided (i.e., N=100), with each optical source generating an optical signal at 10 Gbit/s and at a distinct wavelength out of the wavelength range λ_1 through λ_{100}, then the aggregate optical data rate is one Tbit/s. Following transmission through an optical fiber, a WDM multiplexer combines the one hundred optical signals such that the resulting multiplexed signal contains all optical signals of the wavelength range λ_1 through λ_{100}. The WDM demultiplexer then separates the multiplexed signal into distinct wavelengths to be detected by a hundred optical detectors, each detector operating at 10 Gbits/s. As a result, it is possible to transmit data using the prior art data link at an aggregate rate of 1 Tbit/s.

[0007] It is submitted, however, the aforedescribed prior art data link has a number of disadvantages. In order to increase the total data transmission rate of the prior art data link above approximately 1 Tbit/s, the number of channels, and hence the number of data sources and optical sources used in the data link, must be increased. This condition may be satisfied by narrowing the wavelength differences between channels thus fitting more channels into a given wavelength range λ_1 through λ_N and/or widening the wavelength range between λ_1 and λ_N. However, narrowing the wavelength differences between the channels increases the probability of data transmission error due to potential optical signal overlap and crosstalk and puts a greater demand on the WDM demultiplexer to accurately separate the optical signals into the distinct wavelengths. As is well known in the art, there is only a finite range available for use as the wavelength range λ_1 through λ_N, outside of which significant optical signal loss occurs due to the material properties of the optical fiber as well as other components of an optical communication system, such as repeaters and amplifiers. Therefore, the wavelength range cannot be widened indefinitely using currently available technology, hence it is difficult to increase the number of channels to increase the data transmission rate. Furthermore, increasing the number of different wavelengths traveling simultaneously through the optical fiber also increases the probability of occurrence of undesired, nonlinear optical effects during transmission. Care must be taken to avoid such nonlinear optical effects, thus adding to the overall complexity and cost of this prior art data link at faster data transmission rates. Still further, WDM channels require a guard band on either side of the specific channel wavelength in order to reduce wavelength overlap and crosstalk between channels. Since no data can be transmitted on the guard band, the wavelengths used in the guard band are essentially wasted bandwidth.

[0008] The present invention provides a high speed data link which serves to resolve the problems described above with regard to prior art data links in a heretofore unseen- and highly advantageous way and which provides still further advantages.

SUMMARY OF THE INVENTION

[0009] As will be described in more detail hereinafter, there is disclosed herein a mid-infrared transmitter for providing a light signal in a free-space communication system. In one aspect of the invention, the mid-infrared transmitter includes an arrangement for producing electro-

magnetic radiation having a certain wavelength in a mid-infrared wavelength range. The mid-infrared transmitter further includes an arrangement for modulating the electromagnetic radiation so as to provide a train of light pulses having the certain wavelength as the light signal.

[0010] In another aspect of the invention, a mid-infrared free space data link includes a transmitter arrangement producing a transmitter output. The transmitting arrangement includes a source of light, which light has a certain wavelength in a mid-infrared wavelength range, and a modulator arrangement for modulating the light so as to provide a train of light pulses having the certain wavelength as the transmitter output. The mid-infrared free space data link further includes a directing arrangement for directing the transmitter output to a particular location and, at the particular location, a receiving arrangement configured for receiving the transmitter output.

[0011] In still another aspect of the invention, a method for providing a mid-infrared free space data link includes transmitting a signal containing data. The transmitting step includes generating light having a certain wavelength in a mid-infrared wavelength range, and modulating the light so as to provide a train of light pulses having the certain wavelength as the signal. The method further includes directing the signal toward a particular location and, at the particular location, receiving the signal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The present invention may be understood by reference to the following detailed description taken in conjunction he drawings briefly described below.

[0013] **FIG. 1** is a diagrammatic illustration of a data link designed in accordance with the present invention and employing a superconducting layer and a wavelength converting device to modulate light.

[0014] **FIG. 2** is a diagrammatic illustration of an alternative embodiment of a data link designed in accordance with the present invention.

[0015] **FIG. 3** is a diagrammatic illustration of yet another embodiment of a data link manufactured in accordance with the present invention.

[0016] **FIGS. 4A and 4B** are diagrammatic illustrations of alternative embodiments of an optical transmitter as shown in **FIG. 3**.

[0017] **FIGS. 5A, 5B** and **5C** are diagrammatic illustrations of alternative embodiments of an optical communication system designed in accordance with the present invention.

[0018] **FIG. 6** is a diagrammatic illustration of an embodiment of an electrical receiver suitable for use in the present invention.

DETAILED DESCRIPTION

[0019] Turning now to the drawings, wherein like components are indicated by like reference numbers throughout the various figures, attention is immediately directed to **FIG. 1**, which illustrates one embodiment of a high speed data link, generally indicated by the reference numeral **100**, fabricated in accordance with the present invention. Data link **100** includes a transmitter arrangement **112**, optical fiber **113** and receiver arrangement **114**. Transmitter arrangement **112** includes a data source **116** which provides data input **117** to a superconducting arrangement **118**. Data source **116** can be, for example, a high speed modulating circuit, electronic signal generator, serializer, SONET Add/Drop multiplexer, ATM switch or a combination thereof. Superconducting arrangement **118** is switched between a normal state and a superconducting state according to data input **117**. A light source **120** is used to generate light **122** at a wavelength λ_0 directed toward superconducting arrangement **118**. Light source **120** may be a laser, light emitting diode, etc., as is commonly known in the art. By way of example and not a limitation, a quantum cascade (QC) laser is suitable for use as light source **120**. QC lasers are capable of emitting light over a variety of infrared wavelengths that are compatible with superconducting arrangement **118**, ranging from a few microns to tens of microns at high peak powers of hundreds of milliwatts (See, for example, A. Tredicucci, et al, "High-power inter-miniband lasing in intrinsic superlattices," Applied Physics Letters, 72 (19), pp. 2388-2390). QC lasers are also tunable, thus allowing more flexibility in the specification of superconducting arrangement **118**. Other examples of appropriate light sources include a bismuth antimony BiSb laser (see, for example, A. G. Alksanyan, et al, "Semiconductor laser made of $Bi_{1-x}Sb_x$," Soviet Journal of Quantum Electronics, vol. 14, no. 3, pp. 336-8), germanium laser and gas lasers, such as a laser including a carbon dioxide-pumped cavity with methanol.

[0020] Continuing to refer to **FIG. 1**, superconducting arrangement **118** is designed in such a way that it is transparent to light of wavelength λ_0 when it is in its normal state, and blocks the transmission of light of wavelength λ_0 when it is in its superconducting state. As a result, light **122** is blocked or transmitted according to data input **117**, and light **122** is modulated by superconducting arrangement **118** to produce a series of optical pulses **123** at wavelength λ_0. The details of the switching mechanism of superconducting arrangement **118** are described in detail in U.S. Pat. No. 5,768,002.

[0021] Still referring to **FIG. 1**, it should be noted that the wavelength λ_0 of light **122** and optical pulses **123** is chosen such that wavelength λ_0 is transmitted or blocked by superconducting arrangement **118** depending on whether superconducting arrangement **118** is in its normal or superconducting state. As described in U.S. Pat. No. 5,768,002, superconducting arrangement **118** can perform the function of encoding data input **117** as optical pulses **123** when the wavelength λ_0 is in the far infrared (IR) range (approximately 14 μm or greater). For example, the wavelength λ_0=25 μm is chosen in the embodiment of the present invention shown in **FIG. 1**. Unfortunately, since light of far IR wavelengths attenuate rapidly during transmission through conventional, silica glass optical fiber, it is not practical to directly transmit optical pulses of far IR wavelengths through the optical fiber **113**. To counter this problem, optical pulses **123** are directed into a wavelength converting device **125**, which converts optical pulses **123** at the wavelength λ_0 into optical pulses **126** at a shorter wavelength λ_{conv}. The wavelength λ_{conv} are in the range of approximately 0.5 to 2 μm, preferably on the order of 1.3 or

1.5 μm so as to be compatible with conventional optical fibers. Optical pulses **126** are then directed into one end of optical fiber **113**.

[0022] Optical pulses **126** shown in **FIG. 1** are received at an opposing end of optical fiber **113** by receiving arrangement **114**. Receiving arrangement **114** includes an all-optical (AO) demultiplexer **132**. AO demultiplexer **132** divides optical pulses **126** into a plurality of low data rate, optical pulses **126'** also with wavelength λ_{conv}. Then, each set of divided, low data rate, optical pulses **126'** are detected by an optical detector **134**. For example, AO demultiplexer **132** can be designed to divide optical pulses **126** such that a first data bit goes to a first optical detector, a second data bit goes to a second optical detector, and so on. The optical detectors are, for example, a plurality of interchangeable, generic detectors designed to be sensitive to light of wavelength λ_{conv}. Therefore, while transmitter arrangement **112** generates optical data signals at Tbit/s rates at wavelength λ_{conv} receiver arrangement **114** is able to detect the Tbit/s rate optical data signals using Gbit/s detectors by dividing optical pulses **126** into slower optical pulses **126'**, thus achieving Tbit/s rate transmission through data link **100**.

[0023] Data link **100** takes advantage of the high data rate that is possible with a transmitter arrangement based on a superconducting arrangement to provide a complete, high speed data link. Transmitter arrangement **112** as shown in **FIG. 1** is capable of encoding data input **117** onto optical pulses **126** of wavelength λ_{conv} at data rates of approximately 1 Tbit/s. Unlike the aforementioned prior art data link which requires a plurality of data sources and optical sources operating simultaneously at different wavelengths to achieve an aggregate data transmission rate of 1 Tbit/s, transmitter arrangement **112** is singly capable of transmitting optical data in the form of optical pulses at 1 Tbit/s rates at a single wavelength. It is submitted that this feature of optical source **10** is highly advantageous in at least one respect since, by splitting optical pulses **126** into low data rate, optical pulses **126'**, receiver arrangement **114** is able to detect the high data rate, optical pulses **126** using a series of low speed detectors without the need to use multiple wavelengths and a WDM demultiplexer.

[0024] It should also be understood that only one wavelength, wavelength λ_{conv} is transmitted through optical fiber **113** of data link **100** illustrated in **FIG. 1**. Therefore, potential problems associated with the prior art data such as crosstalk and nonlinear optical effects due to the presence of multiple wavelengths in the optical fiber are eliminated in data link **100**. Furthermore, data link **100** does not require the use of a guard band, thus the available bandwidth outside of wavelength λ_{conv} is not wasted.

[0025] An additional advantage associated with data link **100** resides in the fact that data link **100** is readily upscalable. Since the overall, data transmission rate depends mainly on the speed at which superconducting arrangement **118** can be modulated, as faster materials or switching schemes are developed for the superconducting arrangement such that transmitter arrangement **112** produces higher rate optical pulses **126**, additional optical detectors **134** can be added in receiver arrangement **114** to accommodate the increased data rate without a need to develop faster optical detectors than are currently available commercially today. As faster optical detectors do become available, the number of optical detectors may be accordingly decreased, thus potentially simplifying the high speed data link of the present invention.

[0026] Attention is now directed to **FIG. 2** in conjunction with **FIG. 1**. **FIG. 2** illustrates another data link produced in accordance with the present invention, generally indicated by the reference number **200**. Data link **200** includes a transmitter arrangement **212** as well as optical fiber **113** and receiver arrangement **114**, the latter two components being essentially identical to the corresponding components of data link **100** illustrated in **FIG. 1** with like reference numbers. Therefore, the discussion of data link **200** will concentrate on transmitter arrangement **212** which is modified with respect to transmitter arrangement **112** of data link **100**.

[0027] Like transmitter arrangement **112** of **FIG. 1**, transmitter arrangement **212** shown in **FIG. 2** includes light source **120** which generates light **122** of wavelength λ_0 directed towards superconducting arrangement **118**. Superconducting arrangement **118** is switched between its normal and superconducting states according to data input **117**, thus generating optical pulses **123** of wavelength λ_0. Optical pulses **123** are directed into wavelength converting device **125** which converts optical pulses **123** of wavelength λ_0 into optical pulses **126** of wavelength λ_{conv}.

[0028] However, the way in which data input **117** is generated is different in transmitter arrangement **212** as compared to that of transmitter arrangement **112**. Transmitter arrangement **212** includes a plurality of optical transmitters **150** and **152** arranged to transmit optical modulation pulses in parallel into an optoelectronic (OE) multiplexer **154**. OE multiplexer **154** reads the optical modulation pulses in parallel then serializes the electrical data from the optical modulation pulses, thus generating data input **117**. It should be noted that data input **117** is a serial, electrical signal. For example, commercially-available, 10 Gbit/s optical transmitters, which are well-known in the art, are suitable for use as optical transmitters **150** and **152**. OE multiplexer **154** can be designed to generate data input **117** at rates of one Tbit/s or higher depending on the number of optical transmitters used. In this way, slower optical transmitters can be multiplexed to generate high speed data signals for switching superconducting arrangement **118**, and optical pulses **126** are generated at rates of Tbit/s or higher. OE multiplexer **154** is, for instance, a multiplexer based on Josephson Junction circuitry. Alternatively, the plurality of optical transmitters **150** and **152** and OE multiplexer **154** is replaceable by a system of a plurality of fiber optic transmitters, receivers, optical fibers and a high speed shift register, as described in U.S. Pat. No. 5,768,002.

[0029] Referring now to **FIG. 3**, a diagrammatic illustration of still another embodiment of a data link manufactured in accordance with the present invention, generally indicated by reference numeral **300**, is shown. Data link **300** includes a transmitter arrangement **312**, an optical fiber **313** and a receiver arrangement **314**. Transmitter arrangement **312** includes a series of optical transmitters **212'**. Each optical transmitter **212'** is identical to transmitter arrangement **212** illustrated in **FIG. 2** with a modification that optical transmitter **212'** is designed to generate optical pulses **126'** of a particular wavelength out of the wavelength range λ_{conv1} to λ_{convN} in such a way that no two optical transmitters

generate optical pulses **126'** at the same wavelength. As described in the discussion of **FIG. 2**, each optical transmitter **212'** is capable of generating optical pulses **126'** at rates of Tbit/s or higher.

[0030] The series of optical pulses **126'** are directed into a WDM multiplexer **324** which combines the series of optical pulses **126'** such that the series of optical pulses **126'**, each set of optical pulses **126'** having a distinct wavelength out of the wavelength range λ_{conv1} to λ_{convN}, are together directed into optical fiber **313** as optical pulses **326**. Optical pulses **326** contains all sets of optical pulses **126'** such that all optical data encoded into the series of optical pulses **126'** are transmitted down optical fiber **313** simultaneously. In this way, optical pulses **326** carries optical data signals at an aggregate rate which is greater than Tbit/s.

[0031] Optical pulses **326** are transmitted through optical fiber **313** and into receiver arrangement **314**, where optical pulses **326** are received by a WDM demultiplexer **332**. WDM demultiplexer **332** separates optical pulses **326** back into the series of optical pulses **126'** according to wavelength. Each set of optical pulses **126'** is directed into an optical receiver **114'**, which is identical to receiver arrangement **114** of **FIG. 1** with a modification that AO demultiplexer **132** is designed to divide a set of optical pulses **126'** of at least one particular wavelength out of the wavelength range λ_{conv1} to λ_{convN} into a plurality of low data rate, optical pulses **126"**. Thus, each optical receiver **114'** is capable of receiving optical pulses **126'** at rates of Tbit/s or higher. Furthermore, by using a WDM demultiplexer and a plurality of wavelengths with each wavelength carrying optical data at rates of Tbit/s, receiver arrangement **314** is able to receive optical data at an aggregate rate of much higher than Tbit/s.

[0032] Turning to **FIGS. 4A and 4B**, two possible alternatives for the optical transmitter **212'** are illustrated. Although two specific schemes for the optical transmitter are shown, these configurations are not to be considered as limiting. Various modifications may be made to the optical transmitter alternatives shown in **FIGS. 4A and 4B** while keeping with the spirit of the present invention.

[0033] **FIG. 4A** is a diagrammatic illustration of an optical transmitter **212'A**, which is the X^{th} optical transmitter in a series of N optical transmitters. Optical transmitter **212'A** includes a wavelength converting device **125'** with a pump laser **340** and a nonlinear optical crystal **342**. Pump laser **340** provides a pump beam **344** of a predetermined wavelength λ_{pX} directed at nonlinear optical crystal **342**. Optical pulses **123** from superconducting arrangement **118** are also incident on nonlinear optical crystal **342**. Since the specific wavelength generated by the wavelength converting device **125'** depends on the material characteristics of nonlinear optical crystal **342** and the wavelength of pump laser **340**, the predetermined wavelength λ_{pX} of pump beam **344** is selected such that optical pulses **123** of wavelength λ_0 are converted into optical pulses of a particular wavelength λ_{convX} out of the wavelength range λ_{conv1} to λ_{convN} By using identical nonlinear optical crystals **342** in all optical transmitters **212'** and selecting a suitable pump laser wavelength λ_{pX} for each wavelength converting device **125'**, the series of optical transmitters **212'** are designed in such a way that each optical transmitter **212'** generates optical pulses **126'** of a particular wavelength out of the wavelength range λ_{conv1} to λ_{convN} and no two optical transmitters generate optical pulses **126'** at the same wavelength. For example, each optical transmitter **212'** is equipped with a distinct pump laser which lases at the specific pump wavelength λ_{pX}. Alternatively, every optical transmitter **212'** is equipped with an identical, tunable pump laser and each tunable pump laser is programmed at the factory or in the field to the appropriate wavelength λ_{pX}. In yet another implementation, all wavelength converting devices includes identical pump lasers and a suitable nonlinear optical crystal can be selected for each wavelength converting device **125'** such that each optical transmitter **212'** generates optical pulses **126'** of wavelength λ_{convX} out of the wavelength range λ_{conv1} to λ_{convN} and no two optical transmitters generate optical pulses **126'** at the same wavelength. As another possibility, all wavelength converting devices may include identical pump lasers and nonlinear optical crystals, with each nonlinear optical crystal being provided with, for example, a temperature and/or current control device to tune the material properties of the nonlinear optical crystal such that that each optical transmitter **212'** generates optical pulses **126'** of wavelength λ_{convX} out of the wavelength range λ_{conv1} to λconvN and no two optical transmitters **212'A** generate optical pulses **126'** at the same wavelength. It should be noted that all components (other than wavelength converting device **125'**) of optical transmitter **212'A** are essentially the same as those of optical transmitter **212** shown in **FIG. 2**.

[0034] An alternative scheme for an optical transmitter is shown in **FIG. 4B**, generally indicated by reference numeral **212'B**. Each optical transmitter **212'B** in this case is equipped with a generic, tunable laser as light source **120'** which emits light **122'** of wavelength λ_X, where X=an integer between 1 and N corresponding to the X^{th} optical transmitter **212'B**. All components (other than light source **120'**) of optical transmitter **212'B** are identical to those of optical transmitter **212** shown in **FIG. 2**. Light **122'** is directed at superconducting arrangement **118**, which in turn produces optical pulses **123'** of wavelength λ_X. Each optical transmitter **212'B** in the series of optical transmitters is provided with a generic wavelength converting device **125**. The wavelength λ_X of light **122'** produced at tunable laser of each optical transmitter **212'B** is then tuned to provide light of a distinct wavelength such that wavelength converting device **125** converts the wavelength λ_X of optical pulses **123'** into optical pulses **126'** of a particular wavelength λ_{convX} out of the wavelength range λ_{conv1} to λ_{convN} and no two optical transmitters **212'B** generate optical pulses **126'** at the same wavelength. The aforementioned QC laser is an example of a light source which is suitable for use as the tunable laser in this configuration. A bismuth laser, antimonide laser, germanium laser or a gas laser, such as a laser including a carbon dioxide-pumped cavity with methanol, may also be used in conjunction with an appropriate tuning mechanism (such as a temperature, current and/or magnetic field controller).

[0035] It should be noted that the use of a tunable pump laser as pump laser **340** as shown in **FIG. 4A** or a tunable laser as light source **120'** as shown in **FIG. 4B** adds a routing capability to data link **300** of **FIG. 3**. By tuning the output wavelength of the series of optical transmitters **212'** in data link **300**, it is possible to direct data from any optical transmitter **212'** to any optical receiver **114'**, thus routing the transmitted data to the desired recipient.

[0036] Returning to **FIG. 3**, although data link **300** uses a plurality of wavelengths as in the aforedescribed prior art data link, it is submitted that data link **300** has advantages over the prior art data link. Since data link **300** is capable of transmitting at Tbit/s data rates on each train of wavelength converted optical pulses **126'**, the selection of specific wavelengths out of the wavelength range λ_{conv1} to λ_{convN} is more flexible than in prior art data links, which depend on the packing of as many channels as possible into the limited wavelength range. Data link **300** can achieve multiple Tbit/s data rates with fewer constraints on the wavelengths chosen such that the wavelengths and channel spacings used can be specifically selected to reduce problems such as cross talk and nonlinear optical effects. In addition, although data link **300** requires the use of a guard band on either side of each channel wavelength, the fast data rate capability at each channel and the flexibility in wavelength selection allow more efficient use of the available bandwidth and higher data rates as compared to prior art WDM data links.

[0037] Attention is now directed to FIGS. **5A-5C**, which illustrate alternative embodiments of an optical communication system designed in accordance with the present invention. FIGS. **5A-5C** show optical communication systems **400A-400C**, which correspond to high speed data links **100**, **200** and **300** of FIGS. **1-3**, respectively, where optical fiber **113** is generally replaced by a satellite transmission system **413** in each of FIGS. **1-3**. The transmitter and receiver arrangements of FIGS. **5A-5C** are essentially the same as those shown in FIGS. **1-3**, respectively, therefore explanation of FIGS. **5A-5C** is restricted to the details of the satellite transmission system.

[0038] Satellite transmission system **413** in FIGS. **5A-5C** includes a reflector **415A**, which directs the optical pulses from the corresponding transmitter arrangement toward a satellite **417**. Satellite **417** then redirects the optical pulses toward a desired location where the redirected optical pulses are intercepted by an interceptor arrangement **415B**. The optical pulses intercepted by interceptor arrangement **415B** are received by the corresponding receiving arrangement. Reflector **415A** and interceptor arrangement **415B** are, for example, conformable mirrors (such as the micro-machined membrane mirror manufactured by SY Technology). Conformable mirrors are useful in the satellite transmission system of FIGS. **5A-5C** because they can be used to compensate for possible distortion of the optical pulses. Such distortion in the optical pulses are potentially produced during transmission to and from the satellite due to, for example, atmospheric disturbances. In the case of the embodiments of the optical communication systems shown in FIGS. **5A-5C**, wavelength converting device **125** in each of the transmitter arrangements may be adjusted to produce optical pulses at wavelengths appropriate for satellite communications, such as in the far-infrared wavelengths. Moreover, reflector **415A**, interceptor arrangement **415B** and/or satellite **417** can include an off-axis paraboloid (may be conformable) for focusing or collimating the optical pulses. The conformable mirror and/or off-axis paraboloid as well as other components used in satellite transmission system **413** should be compatible with wavelengths used in free space communication systems such as, for example, wavelengths in the mid-infrared range (3 to 5 μm, 8 to 12 μm, etc.). For example, wavelength converting device **125** can be configured to generate optical pulses **126** in the aforementioned mid-infrared range. Alternatively, a light source capable of producing light **122** in the mid-infrared range can be used as light source **120** in combination with a superconducting material compatible with the mid-infrared range as superconducting arrangement **118** such that frequency converting device **125** may be eliminated altogether. In other words, if light source **120** produces light in the mid-infrared range, superconducting arrangement **118** can be used to produce optical pulses **123** in the mid-infrared range such that optical pulses **123** may be directed toward satellite **417** without the need for frequency converting device **125**. An example of suitable superconducting materials include mercury-based superconductor materials, which have critical temperatures of 134° K and 164° K under pressure. According to the Bardeen Cooper Schreiffer theory a superconductor with a critical temperature of 164° K would have a critical wavelength of 11μm. Therefore a superconductor arrangement **118** made form strained mercury cuprates can be used with light **122** with wavelengths greater than 11 μm. In this way, the high speed data link of the present invention is applicable to free-space communication systems as well as for optical fiber-based systems.

[0039] Turning now to **FIG. 6**, an alternative option to the aforedescribed optical receivers **114** and **114'** is shown. **FIG. 6** illustrates a receiver **514**, which is based on a superconducting detector **540** and is suitable for use in the high speed data link of the present invention. Such use of superconducting films as bolometers or photodetectors are known in the art (see, for example, U.S. Pat. No. 5,155,093 issued to Den et al., U.S. Pat. No. 5,600,172 issued to McDevitt et al. and Roman Soblewski, "Ultrafast dynamics of nonequilibrium quasiparticles in high-temperature superconductors, "*Superconducting and Related Oxides: Physics and Nanoengineering III*, ed. by I. Bozovic and D. Pavuna, *Proc. SPIE*, 3481, 480-491 (1998)). When a train of light pulses containing optical data, such as optical pulses **126** of **FIG. 1**, is incident on superconducting detector **540**, optical pulses **126** are converted into a train of voltage spikes **542**. Voltage spikes **542** are received by an electrical demultiplexer **544**. Electrical demultiplexer **544** performs a task analogous to AO demultiplexer **132** of **FIG. 1** in that, where as AO demultiplexer **132** divides optical pulses **126** into a plurality of low data rate, optical pulses **126'**, electrical demultiplexer **544** divides voltage spikes **542** into a plurality of low data rate, voltage spikes **542'**. Voltage spikes **542'** are received by a plurality of electrical detectors **548**, which can be low speed electrical detectors that are commercially available. Receiver **514** of **FIG. 6** is usable in situations in which it may be desirable to use an electrical signal detection scheme rather than an optical signal detection scheme.

[0040] Since the high speed data link and associated method disclosed herein may be provided in a variety of different configurations and the method may be practiced in a variety of different ways, it should be understood that the present invention may be embodied in many other specific ways without departing from the spirit or scope of the invention. For example, an optical detector may be configured in essentially unlimited number of ways to cooperate with an AO demultiplexer in such a way that a series of optical pulses are divided into lower rate, optical pulses by the AO demultiplexer and detected by the optical detector. Furthermore, additional optical devices such as, but not limited to, optical amplifiers, switches, routers, and repeaters may be inserted in-line with an optical fiber for transmitting optical pulses from a transmitter arrangement to a receiver

arrangement. Still further, the optical fiber may be eliminated as the transmission medium between the transmitter and receiver arrangements. In this way, wavelengths outside of the optical fiber transmission window can be used and the data link of the present invention becomes applicable to data transmission using electromagnetic waves outside of the optical wavelength range (microwave data transmission, for example). Such modifications are considered to be within the scope of the present invention so long as the teachings herein are applied. Therefore, the present examples are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope of the appended claims.

What is claimed is:

1. A mid-infrared transmitter for providing a light signal in a free-space communication system, said transmitter comprising:

means for producing electromagnetic radiation, said electromagnetic radiation having a certain wavelength in a mid-infrared wavelength range; and

means for modulating said electromagnetic radiation so as to provide a train of light pulses having said certain wavelength as said light signal.

2. The mid-infrared transmitter of claim 1 wherein said electromagnetic radiation producing means includes a laser diode.

3. The mid-infrared transmitter of claim 2 wherein said laser diode is a quantum cascade laser.

4. The mid-infrared transmitter of claim 2 wherein said laser diode is a germanium laser.

5. The mid-infrared transmitter of claim 2 wherein said laser diode is an antimonide laser.

6. The mid-infrared transmitter of claim 1 wherein said mid-infrared wavelength range includes wavelengths between 3 and 5 microns.

7. The mid-infrared transmitter of claim 1 wherein said mid-infrared wavelength range includes wavelengths between 8 and 12 microns.

8. The mid-infrared transmitter of claim 1 wherein said modulating means is configured to modulate said electromagnetic radiation after said electromagnetic radiation has been produced by said electromagnetic radiation producing means so as to produce said train of light pulses.

9. The mid-infrared transmitter of claim 1 wherein said electromagnetic radiation producing means is configured to accept an electrical signal, and wherein said modulating means includes means for providing said electrical signal so as to provide said train of light pulses.

10. The mid-infrared transmitter of claim 9 wherein said input signal is a driving voltage, and wherein said modulating means is configured to modulate said driving voltage and to supply said driving voltage, so modulated, to said electromagnetic radiation producing means so as to provide said train of light pulses.

11. The mid-infrared transmitter of claim 9 wherein said input signal is a driving current, and wherein said modulating means id configured to modulate said driving current and to supply said driving current, so modulated, to said electromagnetic radiation producing means so as to provide said train of light pulses.

12. The mid-infrared transmitter of claim 1 wherein said electromagnetic radiation producing means is tunable such that said certain wavelength of said electromagnetic radiation is consequently tunable over a range of wavelengths within said mid-infrared wavelength range.

13. The mid-infrared transmitter of claim 1 further comprising:

a plurality of additional means for producing a plurality of additional electromagnetic radiation, each of said plurality of additional electromagnetic radiation having a distinct wavelength in said mid-infrared wavelength range; and

a plurality of additional means, each cooperating with at least one of said additional electromagnetic radiation producing means, for providing a plurality of trains of light pulses as said light signal, each of said plurality of trains of light pulses having said distinct wavelength.

14. The mid-infrared transmitter of claim 1 further comprising means for directing said train of light pulses toward a particular location.

15. The mid-infrared transmitter of claim 14 wherein said directing means is adjustable to compensate for possible distortion in said light pulses, said distortion potentially being produced during transmission of the light pulses toward said particular location.

16. The mid-infrared transmitter of claim 15 wherein said directing means includes a conformable mirror.

17. A mid-infrared free space data link comprising:

a transmitter arrangement producing a transmitter output, said transmitting arrangement including

a source of light having a certain wavelength in a mid-infrared wavelength range,

a modulator arrangement for modulating said light so as to provide a train of light pulses having said certain wavelength as said transmitter output;

a directing arrangement for directing said transmitter output to a particular location; and

at said particular location, a receiving arrangement configured for receiving said transmitter output.

18. The mid-infrared free space data link of claim 17 wherein said directing arrangement includes a conformable mirror.

19. The mid-infrared free space data link of claim 17 wherein said mid-infrared wavelength range includes wavelengths between 3 and 5 microns.

20. The mid-infrared free space data link of claim 17 wherein said mid-infrared wavelength range includes wavelengths between 8 and 12 microns.

21. The mid-infrared free space data link of claim 17 wherein said source includes a laser diode.

22. The mid-infrared free space data link of claim 21 wherein said laser diode is a quantum cascade laser.

23. The mid-infrared free space data link of claim 21 wherein said laser diode is a germanium laser.

24. The mid-infrared free space data link of claim 21 wherein said laser diode is an antimonide laser.

25. The mid-infrared free space data link of claim 17 wherein said modulator arrangement is configured to modulate said light after said light has been produced by said source so as to produce said train of light pulses.

26. The mid-infrared free space data link of claim 17 wherein said source is configured to accept an input signal,

and wherein said modulator arrangement is configured to modulate said input signal so as to provide said train of light pulses.

27. The mid-infrared free space data link of claim 26 wherein said input signal is a driving voltage and wherein said modulator arrangement is configured to modulate said driving voltage so as to provide said train of light pulses.

28. The mid-infrared free space data link of claim 26 wherein said input signal is an input current and wherein said modulator arrangement is configured to modulate said input current so as to provide said train of light pulses

29. The mid-infrared free space data link of claim 17 wherein said source is tunable such that said certain wavelength of said light is consequently tunable over a range of wavelengths within said mid-infrared range.

30. The mid-infrared free space data link of claim 17 wherein said receiver further includes

a plurality of additional sources of additional light, each of said plurality of additional light having a distinct wavelength in said mid-infrared wavelength range; and

a plurality of additional arrangements, each cooperating with at least one of said additional sources, for providing a plurality of trains of light pulses as said transmitter output, each of said plurality of trains of light pulses having said distinct wavelength.

31. A method for providing a mid-infrared free space data link, said method comprising:

transmitting a signal containing data, said transmitting step including

generating light having a certain wavelength in a mid-infrared wavelength range,

modulating light so as to provide a train of light pulses having said certain wavelength as said signal;

directing said signal toward a particular location; and

at said particular location, receiving said signal.

32. The method of claim 31 wherein said directing step includes adjusting said directing means to compensate for possible distortion in said signal, said distortion being potentially produced during transmission of said signal toward said particular location.

33. The method of claim 31 wherein said adjusting step includes using a conformable mirror.

34. A method for providing a mid-infrared free space data link for communicating a data signal, said method comprising:

providing an input signal,

generating, in response to said input signal, light having a certain wavelength in a mid-infrared wavelength range; wherein said step of providing said input signal includes configuring said input signal so as to provide a train of light pulses having said certain wavelength as said signal;

directing said data signal toward a particular location; and

at said particular location, receiving said signal.

35. The method of claim 34 wherein said step of providing said input signal includes the step of supplying an input voltage as said input signal.

36. The method of claim 34 wherein said step of providing said input signal includes the step of supplying an input current as said input signal.

* * * * *